APPENDIX D

Minimum Standards for Liquefaction Investigations and Evaluations

Sensitive Lands Evaluation & Development Standards (SLEDS)
Chapter 19.72, COTTONWOOD HEIGHTS CODE OF ORDINANCES

1.0 INTRODUCTION

The procedures outlined in this Appendix D are intended to provide consultants with a general outline for performing liquefaction studies and to specify the city's expectations concerning such studies. These standards constitute the ***minimum*** level of effort required in conducting liquefaction studies in the city. Considering the complexity inherent in performing liquefaction studies, additional effort beyond the minimum standards presented herein may be required at some sites to adequately address the liquefaction potential at the site. The information presented in this Appendix D does not relieve consultants of their duty to perform additional geologic or geotechnical engineering analyses that is required by the city or otherwise reasonably necessary to adequately assess the liquefaction potential at a site.

1.1 ***Purposes*.** The purposes of establishing minimum standards for liquefaction investigations in the city are to:

(a) Protect the health, safety, welfare, and property of the public by minimizing the potentially adverse effects of liquefaction and related hazards;

(b) Assist property owners and land developers in conducting reasonable and adequate studies;

(c) Provide consulting engineering geologists and geotechnical engineers with a common basis for preparing proposals, conducting studies, and mitigation; and

(d) Provide an objective framework for regulatory review of liquefaction study reports.

1.2 ***References and Sources***. The minimum standards presented herein were developed, in part, from the following sources:

(a) CDMG Special Publication 117, Guidelines for evaluating and mitigating seismic hazards in California (1997).

(b) Recommended procedures for implementation of DMG special publication 117, guidelines for analyzing and mitigating liquefaction hazards in California (Martin and Lew, 1999).

(c) Proceedings of the NCEER Workshop on Evaluation of Liquefaction Resistance of Soils, Technical Report NCEER-97-0022 (Youd and Idriss, 1997).

(d) Liquefaction Resistance of Soils: Summary Report from the 1996 and 1998 NCEER/NSF Workshops on Evaluation of Liquefaction Resistance of Soils, Journal of Geotechnical and Environmental Engineering, (Youd et al., 2001).

(e) Salt Lake County geologic hazards ordinance (2002).

(f) Southern California Earthquake Center (1999), Recommended Procedures for Implementation of DMG Special Publication 117, Guidelines for analyzing and mitigating liquefaction in California.

1.3 ***Properties Requiring Liquefaction Analyses***. The Liquefaction Hazard Study Area Map (Map 3 in Appendix A of Chapter 19.72 of this code) depicts generalized liquefaction susceptibility for the city, and shall be used to determine whether or not a site-specific liquefaction assessment is required for a particular project.

(a) The Liquefaction Hazard Study Area Map is based on a regional-scale investigation of Salt Lake County; therefore, the liquefaction potential at a specific site may be different (higher or lower) than the liquefaction potential suggested by the map. Such map may not identify all areas that have potential for liquefaction; a site located outside of an area of required study is not necessarily free from liquefaction hazard, and the study areas do not always include lateral spread run-out areas. The Liquefaction Hazard Study Area Map is available from the city's planning department.

(b) Chapter 19.72 requires a site-specific liquefaction study to be performed prior to approval of a project based on the liquefaction potential. The liquefaction potential for each individual soil layer in a CPT sounding or at the sampling frequency interval in a boring should be assessed. If the factor of safety for liquefaction is less than 1, then an estimate of the settlement for each layer should be completed. The total anticipated settlement should be defined in the analysis and report. All liquefaction analyses should be completed in accordance with DMG Special Publication 117 (1999), as amended or superceded.

1.4 ***Roles of Engineering Geology and Geotechnical Engineering***.

(a) The study of liquefaction hazard is an interdisciplinary practice. The site investigation report must be prepared by a qualified engineering geologist or geotechnical engineer, who must have competence in the field of seismic hazard evaluation and mitigation, and be reviewed by a qualified geotechnical engineer, also competent in the field of seismic hazard evaluation and mitigation.

(b) Because of the differing expertise and abilities of qualified engineering geologists and geotechnical engineers, the scope of the site investigation report for the project may require that both types of professionals prepare and review the report, each practicing in the area of their expertise. Involvement of both a qualified engineering geologist and geotechnical engineer will generally provide greater assurance that the hazard is properly identified, assessed, and mitigated.

(c) Liquefaction analyses are the responsibility of the geotechnical engineer, although the engineering geologist should be involved in the application of screening criteria (section 3.0, steps 1 and 2) and general geologic site evaluation (section 4.1) to map the likely extent of liquefiable deposits and shallow groundwater. Engineering properties of earth material shall be evaluated by the geotechnical engineer. The performance of the quantitative liquefaction analysis resulting in a numerical factor of safety and quantitative assessment of settlement and liquefaction-induced permanent ground displacement shall be performed by geotechnical engineers. The geotechnical and civil engineers shall develop all mitigation and design recommendations. Ground motion parameters for use in quantitative liquefaction analyses may be provided by either the engineering geologist or the geotechnical engineer.

1.5 ***Minimum Qualifications of the Licensed Professional***. Liquefaction analyses must be performed by engineering geologists and geotechnical engineers, qualified as provided in Chapter 19.72.

2.0 GENERAL REQUIREMENTS

Except for the derivation of input ground motion (see Section 5.0, below), liquefaction studies should be performed in general accordance with the latest version of Recommended Procedures for Implementation of DMG Special Publication 117, Guidelines for Analyzing and Mitigating Liquefaction in California (Martin and Lew, 1999). Additional protocol for liquefaction studies is provided in Youd and Idriss (1997), cited above.

3.0 PRELIMINARY SCREENING FOR LIQUEFACTION

(a) The Liquefaction Hazard Study Area Map is based on broad regional studies and does not replace site-specific studies. The fact that a site is located within a Liquefaction Hazard Study Area does not mean that there is a significant liquefaction potential at the site, only that a study shall be performed to determine if such potential is present.

(b) Soil liquefaction is caused by strong seismic ground shaking where saturated, cohesionless, granular soil undergoes a significant loss in shear strength that can result in settlement and permanent ground displacement. Surface effects of liquefaction include settlement, bearing capacity failure, ground oscillations, lateral spread and flow failure. It has been well documented that soil liquefaction may occur in clean sands, silty sands, sandy silt, non-plastic silts and gravelly soils. Research shows that the following conditions must be present for liquefaction to occur:

(i) Soils *must be* submerged below the water table;

(ii) Soils *must be* loose to moderately dense;

(iii) Ground shaking *must be* relatively intense; and

(iv) The duration of ground shaking *must be* sufficient for the soils to generate seismically-induced excess pore water pressure and lose their shearing resistance.

(c) The following screening criteria may be applied to determine if further quantitative evaluation of liquefaction hazard is required:

(i) If the estimated maximum past, current, and future groundwater levels (i.e., the highest groundwater level applicable for liquefaction analyses) are determined to be deeper than 50 feet below the existing ground surface or proposed finished grade (whichever is deeper), liquefaction studies are not required. For soil materials that are located above the level of the groundwater, a quantitative assessment of seismically induced settlement is required.

(ii) If "bedrock" or similar lithified formational material underlies the site, those materials need not be considered liquefiable and no analysis of their liquefaction potential is necessary.

(iii) If the corrected standard penetration blow count, $(N1)_{60}$, is greater than or equal to 33 in all samples with a sufficient number of tests, liquefaction assessments are not required. If cone penetration test soundings are made, the corrected cone penetration test tip resistance, qc1N, should be greater than or equal to 180 tsf in all soundings in sand materials, otherwise liquefaction assessments are needed.

(d) If plastic soil (PI $\geq$ 20) materials are encountered during site exploration, those materials may be considered non-liquefiable. Additional acceptable screening criteria regarding the effects of plasticity on liquefaction susceptibility are presented in Boulanger and Idriss (2004), Bray and Sancio (2006), and Seed and others (2003).

(e) If the screening investigation clearly demonstrates the absence of liquefaction hazards at a project site and the City concurs, the screening investigation will satisfy the site study report requirement for liquefaction hazards. If not, a quantitative evaluation is required to assess the liquefaction hazards.

(f) An important part of a liquefaction analysis is the potential for lateral spreading. Any open face and/or sloped sites should be assessed for the potential for lateral spreading. Mitigation measures should be provided in the analysis and report with respect to this hazard.

4.0 FIELD INVESTIGATIONS

Geotechnical field investigations are routinely performed for new projects as part of the normal development and design process. Geologic reconnaissance and subsurface explorations are normally performed as part of the field exploration program even when liquefaction does not need to be investigated.

4.1 *Geologic Reconnaissance*.

(a) Geologic research and reconnaissance are important to provide information to define the extent of unconsolidated deposits that may be prone to liquefaction. Such information should be presented on geologic maps and cross sections and provide a description of the formations present at the site that includes the nature, thickness, and origin of Quaternary deposits with liquefaction potential. There also should be an analysis of groundwater conditions at the site that includes the highest recorded water level and the highest water level likely to occur under the most adverse foreseeable conditions in the future.

(b) During the field investigation, the engineering geologist should map the limits of unconsolidated deposits with liquefaction potential. Liquefaction typically occurs in cohesionless silt, sand, and fine-grained gravel deposits of Holocene to late Pleistocene age in areas where the groundwater is shallower than about 50 feet.

(c) Shallow groundwater may exist for a variety of reasons, some of which are of natural and or manmade origin. Landscape irrigation, on-site sewage disposal, and unlined manmade lakes reservoirs, and storm-water detention basins may create a shallow groundwater table in sediments that were previously unsaturated.

4.2 *Subsurface Explorations*.

(a) Subsurface explorations shall consist of drilled-borings and/or cone penetration tests (CPTs). The exploration program shall be planned to determine the soil stratigraphy, groundwater level, and indices that could be used to evaluate the potential for liquefaction by either in situ testing or by laboratory testing of soil samples. Borings and CPT soundings must penetrate a minimum of 50 feet below final ground surface.

(b) For saturated cohesionless soils where the SPT $(N1)_{60}$ values are less than 15, or where CPT tip resistances are below 60 tsf, grain-size analyses, hydrometers tests, and Atterberg Limits tests shall be performed on these soils to further evaluate their potential for permanent ground displacement (Youd et al., 2002) and other forms of liquefaction-induced ground failure and settlement. In addition, it is also recommended that these same tests be performed on saturated cohesionless soils with SPT $(N1)_{60}$ values between 15 and 30 to further evaluate the potential for liquefaction-induced settlement.

(c) Where a structure may have subterranean construction or deep foundations (e.g., caissons or piles), the depth of investigation should extend to a depth that is a minimum of 20 feet (6 m) below the lowest expected foundation level (e.g., caisson bottom or pile tip) or 50 feet (15 m) below the existing ground surface or lowest proposed finished grade, whichever is deeper. If, during the study, the indices to evaluate liquefaction indicate that the liquefaction potential may extend below that depth, the exploration should be continued until a significant thickness (at least 10 feet or 3 m, to the extent possible) of nonliquefiable soils are encountered.

5.0 GROUND MOTION FOR LIQUEFACTION SUSCEPTIBILITY AND GROUND DEFORMATION ANALYSES

(a) The two controlling faults that would most affect the city are the Salt Lake City and Provo segments of the Wasatch Fault Zone (WFZ). Repeated Holocene movement has been well documented along both segments (Black and others, 2003). Studies along the Provo segment of the WFZ indicate a recurrence interval of about 1150 years (Olig, and others, 2006; later revised, Olig, 2007) and the most recent event being about 500 to 650 years ago (Black and others, 2003; Olig, and others, 2006). Studies along the Salt Lake City segment of the WFZ indicate a recurrence interval of about 1300 years and the most recent event being about 1300 years ago (Lund, 2005). Based on the paleoseismic record of the Salt Lake City segment and assuming a time-dependent model, McCalpin (2002) estimates a conditional probability (using a log-normal renewal model) of 16.5% in the next 100 years (8.25% in the next 50 years) for a M>7 surface-faulting earthquake. Therefore, using a time-dependent rather than Poisson or random model for earthquake recurrence, the likelihood of a large surface-faulting earthquake on the Salt Lake City segment of the WFZ is relatively high and therefore the Salt Lake City segment is considered the primary controlling fault for deterministic analyses.

(b) Concerning design ground accelerations for liquefaction analyses, the city prefers a probabilistic approach to determining the likelihood that different levels of ground motion will be exceeded at a particular site within a given time period. In order to more closely represent the seismic characteristics of the WFZ and to better capture this possible high likelihood of a surface-faulting earthquake on the Salt Lake City segment, design ground motion parameters for liquefaction analyses shall be based on the peak accelerations with a 2.0 percent probability in 50 years (2,500-year return period). Peak bedrock ground motions can be readily obtained via the internet from the United States Geological Survey (USGS) National Seismic Hazard Maps, Data and Documentation web page (USGS, 2002), which is based on Frankel and others (2002). PGAs obtained from the USGS (2002) web page should be adjusted for effects of soil/rock (site-class) conditions in accordance with Seed and others (2001) or other appropriate methods that consider the site-specific soil conditions and their potential for amplification/ deamplification of the high frequency strong motion.

6.0 REMEDIAL DESIGN

Sites, facilities, buildings, structures and utilities that are founded on or traverse liquefiable soils may require further remedial design and/or relocation to avoid liquefaction-induced damage. These should be investigated and evaluated on a site-specific basis with sufficient geologic and geotechnical evaluations to support the remedial design and/or mitigative plan. This design or plan may include changes/modifications to the soil, foundation system, structural frame or support of the building, etc. and should be reviewed and approved by the city.

7.0 SUBMITTALS

(a) Submittals for review shall include boring logs; geologic cross-sections; laboratory data; discussions pertaining to how idealized subsurface conditions and parameters used for analyses were developed; analytical results, including computer output files (on request); and summaries of the liquefaction analyses and conclusions regarding liquefaction potential and likely types and amounts of ground failure.

(b) Subsurface geologic and groundwater conditions must be illustrated on geologic cross-sections and must be utilized by the geotechnical engineer for the liquefaction analyses. If on-site sewage or storm-water disposal exists or is proposed, the liquefaction analyses shall include the effects of the effluent plume on liquefaction potential.

(c) The results of any liquefaction analyses must be submitted with pertinent backup documentation (i.e., calculations, computer output, etc.). Printouts of input data, output data (on request), and graphical plots must be submitted for each computer-aided liquefaction analysis. In addition, input data files, recorded on diskettes, CDs, or other electronic media, may be requested to facilitate the city's review.